

# Deep Underground Science and Engineering Laboratory at Homestake

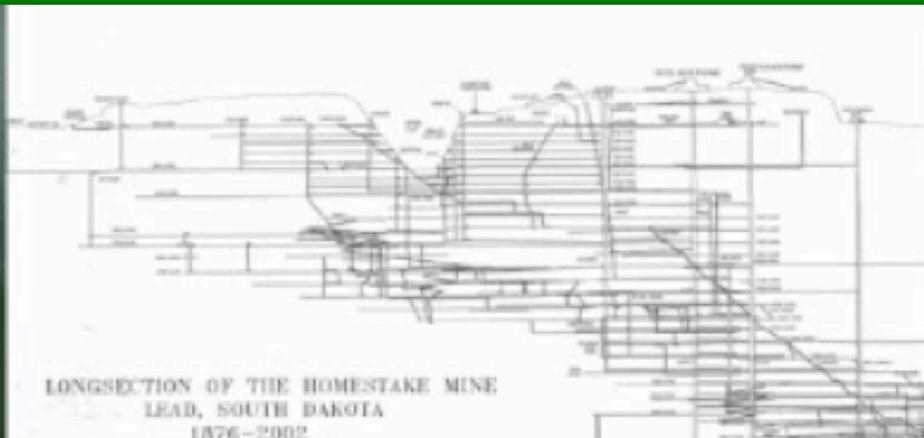
Kevin T. Lesko  
UC Berkeley  
May 2008



South Dakota  
Science and Technology  
Authority

Homestake Mining  
Company

Administration Building  
630 East Summit Street

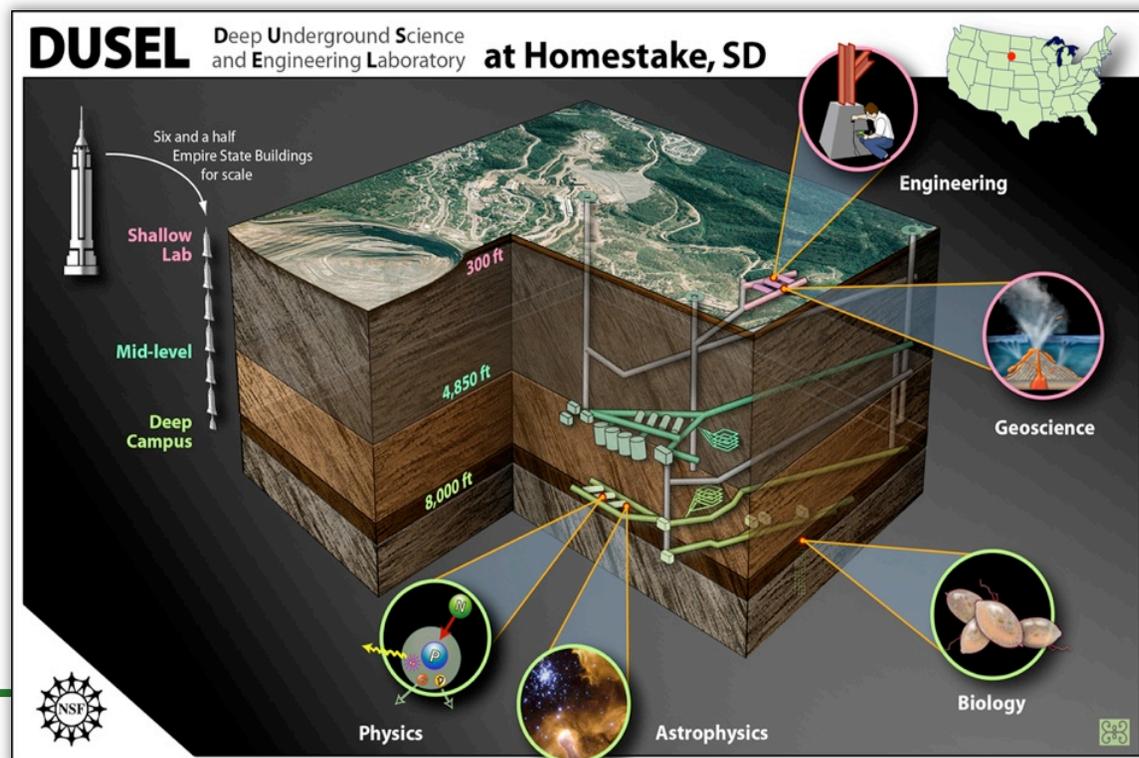


# Outline of Presentation

- The U.S. Deep Underground Science and Engineering Laboratory at Homestake
  - Status of the NSF's Proposal
    - Scope
    - Timetable
    - Recent Milestones
  - DUSEL's Physics Programs
- The Sanford Laboratory
  - Current Status of Facility Reentry
  - Early Implementation Science Program

# Homestake DUSEL Proposal

- NSF's Major Research Equipment and Facility Construction Effort
  - Facility
  - Initial Suite of Experiments
    - Facility Requirements
- Multidisciplinary
  - Physics
  - Geology
  - Biology
  - Engineering
  - Education



# DUSEL Progress

- **DUSEL Three-Step Process**
  - S-1 Assess the Science -- DeepScience
  - S-2 Project Science onto Sites -- CDRs
  - S-3 Select a site -- Homestake
    - \$15M, 3 year planning grant with UCB
- **DUSEL as an MREFC (Major Research Equipment and Facilities Construction)**
  - Recommendation to Advance to *Readiness*
  - ~\$500 - 600M
    - ~\$250M Facility
    - ~\$250M Initial Suite of Experiments
  - Physics Driven, but Multidisciplinary Facility

# Community DUSEL Activities

- S-1: culminated in Deep Science
- November 07 Town Meetings
- DEDC Follows on from S-1
  - Steve Elliott (LANL) Phy
  - Derek Elsworth (Penn State) Geo/Eng
  - Daniela Leitner (LBNL) Phys
  - Larry Murdoch (Clemson) Geo/Eng
  - T.C. Onstott (Princeton) Geo/Bio
  - Hank Sobel (UCI) Phy
- April Homestake Workshops to begin defining Initial Suite Experiments Proposals -- S-4



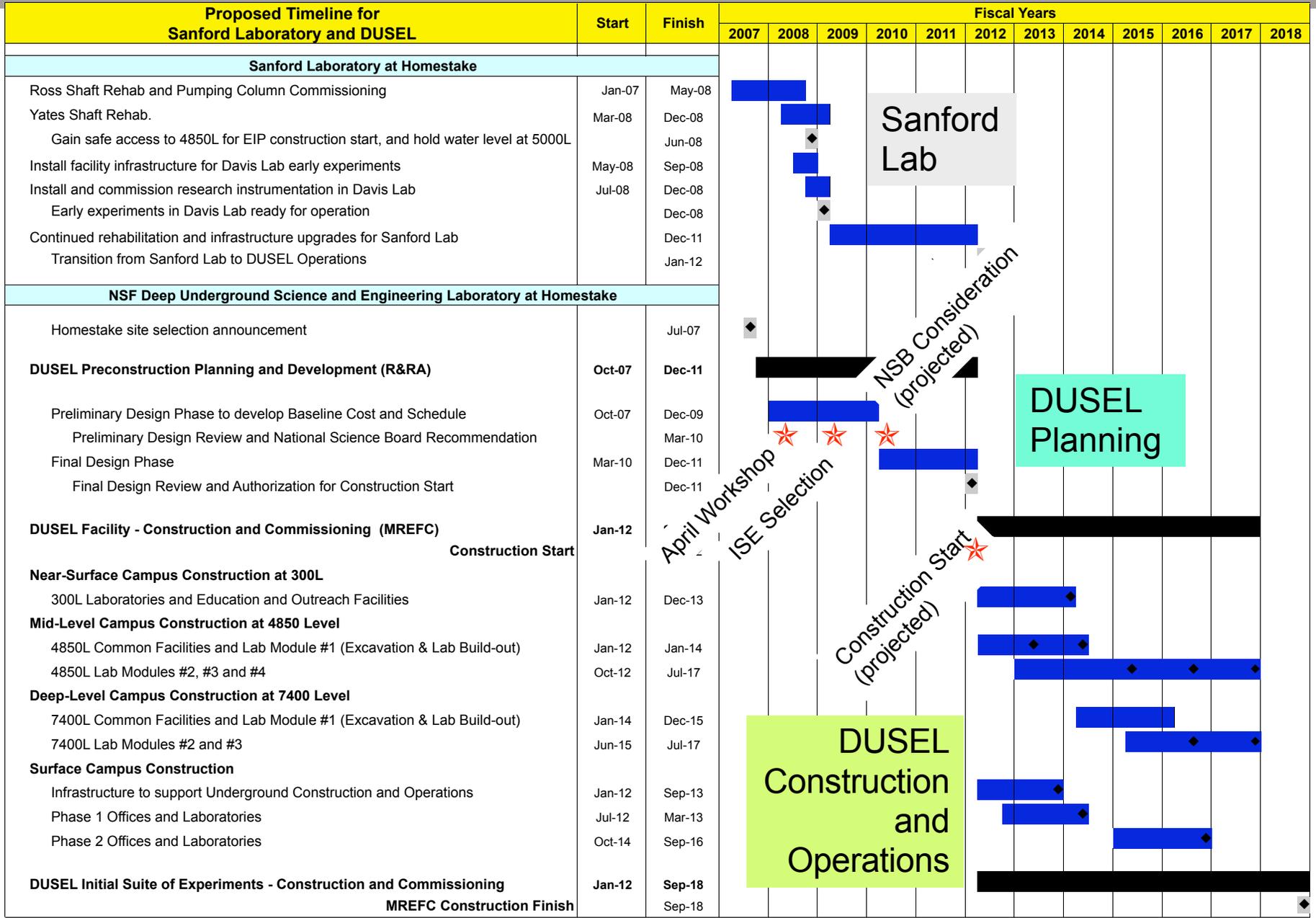
# The Next Round of Solicitations

- **S-4 Develop Superset of Experiments**
  - Provide \$15M over 3 years to develop ISE plans
  - Any day now...
  - All disciplines
- **S-5 Select Initial Suite of Experiments**
  - S-4 is neither necessary nor sufficient for ISE
  - There are additional “on ramps” for experiments other than NSF “S-x” solicitations

# Significant Milestone for Initial Suite of Experiments

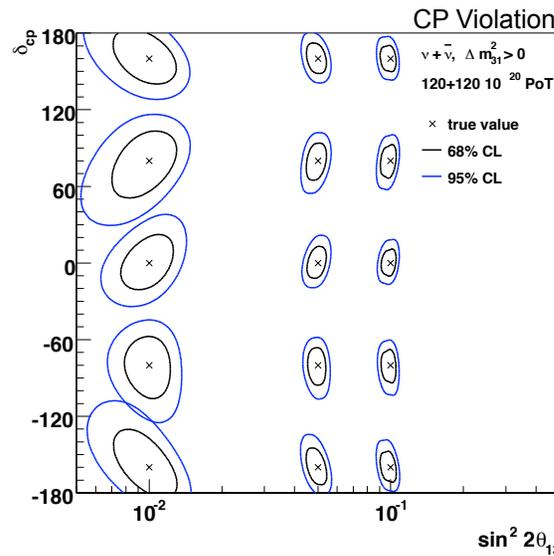
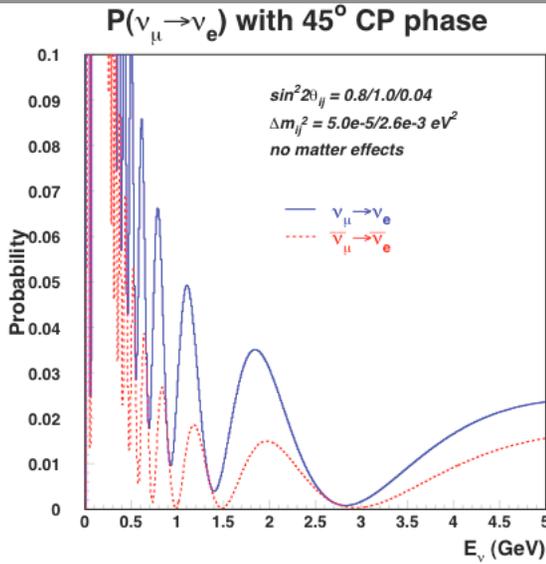
- 
- November 2007 Town Meeting
  - ★ ● April 2008 Lead Workshops
  - Late Spring S-4 Solicitation Announcement
  - July 2008 Internal Review of DUSEL
  - Fall 2008 S-4 Funds for Experiment PDRs
  - December 2008 NSF Review of DUSEL
  - ★ ● Summer 2009 Review of ISE by NSF Panel
  - Summer/Fall 2009 Integration ISE and Facility
  - Fall 2009 Completion of DUSEL PDR & Review
  - ★ ● Winter 2009-10 Presentation to and Review by NSF
  - March 2010 Presentation to NSB
  - ★ ● FY2012 MREFC funding (projected)

# Milestone Schedule

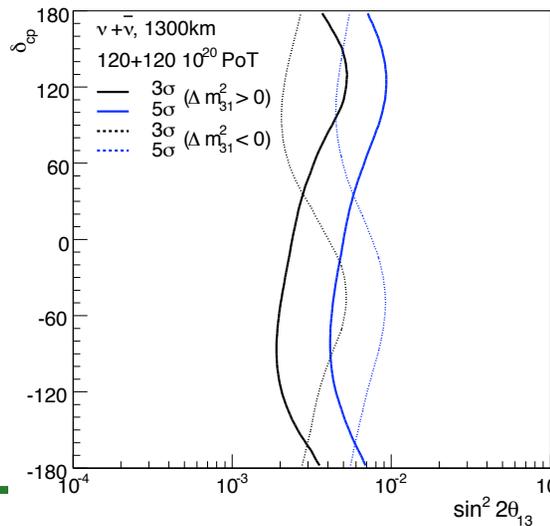


# Physics Motivations: Long Baseline Neutrinos

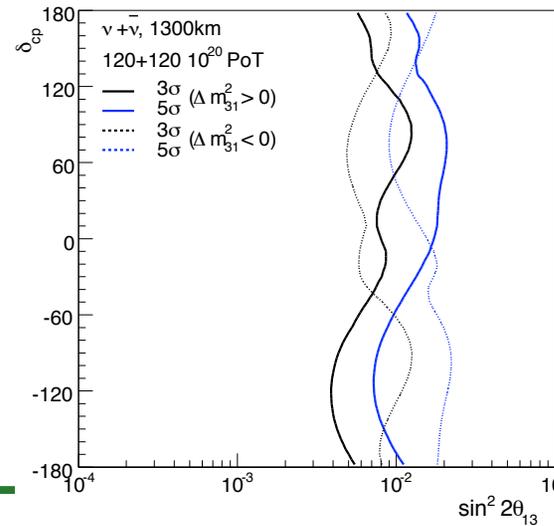
Requires Large  
Detectors, Modest  
Depths (~ 100 - 1000 m)  
and Long Distances from  
 $\nu$  Sources (> 1000 km)



Reach in  $\theta_{13}$



Reach in Mass Hierarchy



Program Highlights  
include significant  
reach and discovery  
potential with long  
baseline neutrinos  
including:

$\theta_{13}$   
Mass Hierarchy  
CP violation

# Physics Motivations: Nucleon Decay

Nonzero Baryon Number and assumptions of  $B=0$  at  $T=0$  suggest proton decay

In the framework of GUTs

$M_p$  = proton mass

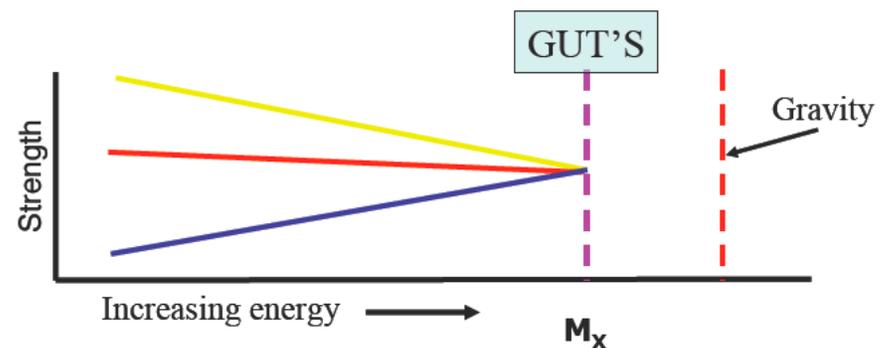
$M_U$  = Unification Mass Scale

$a_U \sim 1/30$

$\therefore \tau_p \sim 10^{36}$  years

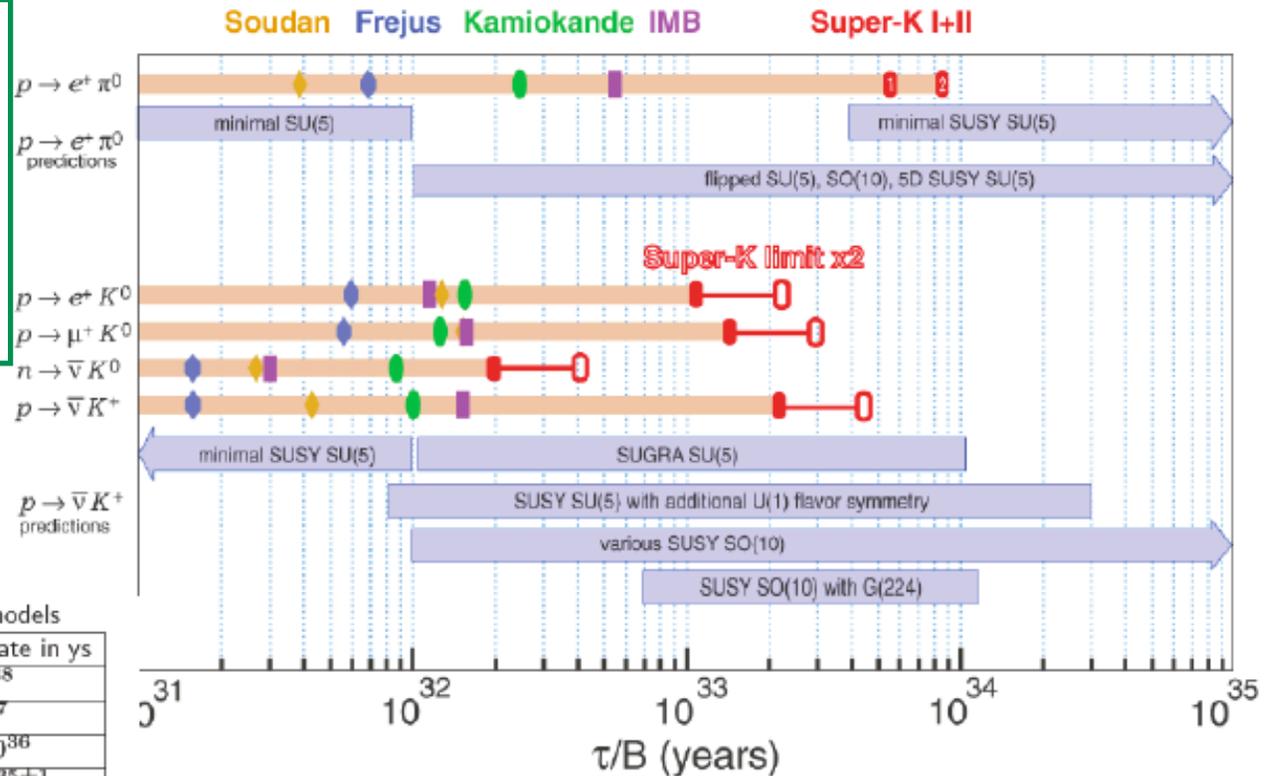
$$\frac{1}{\tau_p} = a_U^2 \frac{M_p^5}{M_U^4}$$

Strong  
Electro-magnetic  
Weak



# Limits for Various Decay Channels

Requires Very Large Detectors, Modest Depths (~ 1500 m), Stable and Long-term Excavations



Lifetime estimates for  $p \rightarrow e^+ \pi^0$  for various models

| Ref  | Model                   | Lifetime estimate in ys       |
|------|-------------------------|-------------------------------|
| LMPR | Non-SUSY GUTs           | $10^{33-38}$                  |
| DP   | SU(5)                   | $\sim 10^{37}$                |
| JH   | SUSY GUTs               | $1.6 \times 10^{36}$          |
| JCP  | SUSY-SO(10)             | $\sim 5 \times 10^{35 \pm 1}$ |
| HM-R | 5D models               | $\sim 4 \times 10^{36}$       |
| KR   | 5D -SO(10)              | $\sim 7 \times 10^{33 \pm 2}$ |
| BCEW | 6D models               | $\sim 5 \times 10^{34 \pm 1}$ |
| KW   | D-brane models          | $(0.8 - 1.9) \times 10^{36}$  |
| PR   | Black holes, worm holes | $\sim 10^{45}$                |

Proton lifetime estimates for  $p \rightarrow \bar{\nu} K^+$  for various models

|              | Model              | Lifetime/ys                            |
|--------------|--------------------|--|
| BPS, EW, DMN | SUSY SU(5)         | $\sim 10^{34}$                         |
| BPW          | SUSY SO(10)        | $(1/3 - 2) \times 10^{34}$             |
| LR           | SUSY SO(10)        | $(6.6 - 3 \times 10^2) \times 10^{33}$ |
| DMM, NS      | SUSY GUTs          | $\geq (2 - 3) \times 10^{33}$          |
| AN           | Calabi-Yau Strings | $\sim 10^{34-35}$                      |

from Hank Sobel

# Program: FNAL to Homestake ~ 1290 km

FNAL (L~1290 km) 700 kW  
@ 120 GeV  $\rightarrow$   $6 \times 10^{20}$  POT /yr  
by ~ 2012



Then Project X: 2.3 MW  
@ 60 - 120 GeV as early as 2016

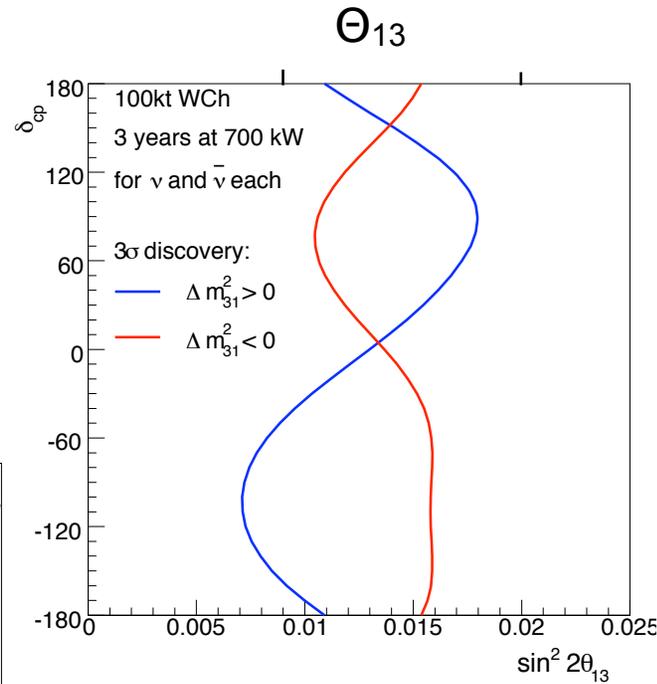
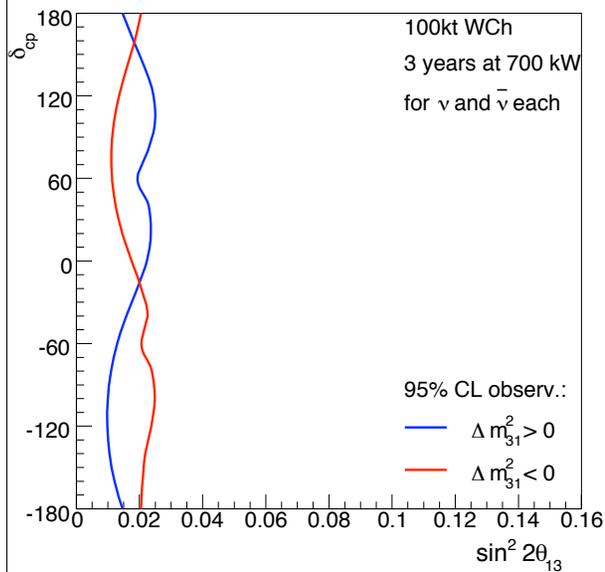


# Physics with 100-kt Water Cherenkov Detector & 700kW Beams @ 120 GeV 3 years each $\nu+\bar{\nu}$

1kt LAr  $\approx$  3kt H<sub>2</sub>O

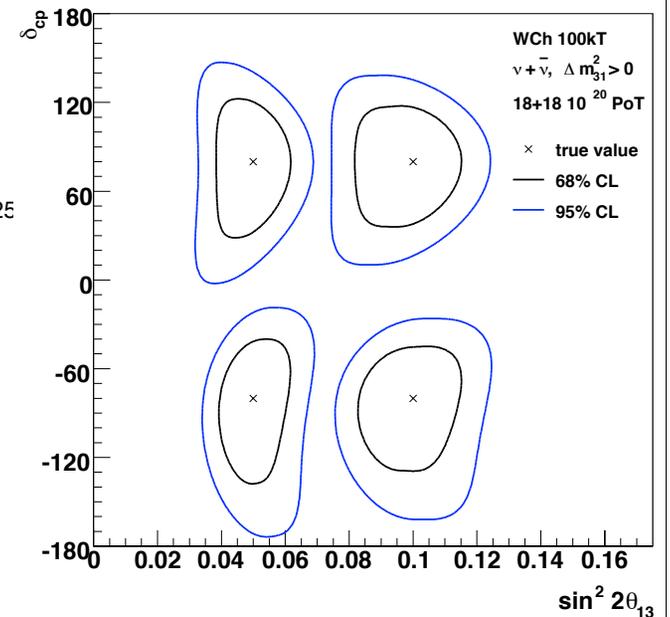
18x10<sup>20</sup> POT each

## Mass Hierarchy



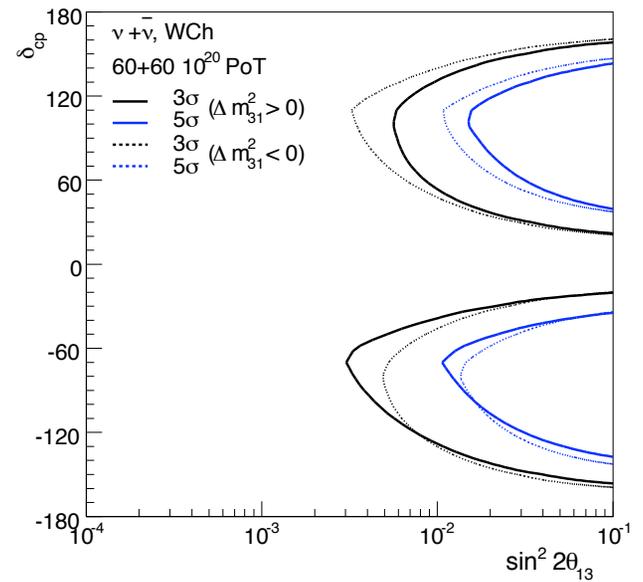
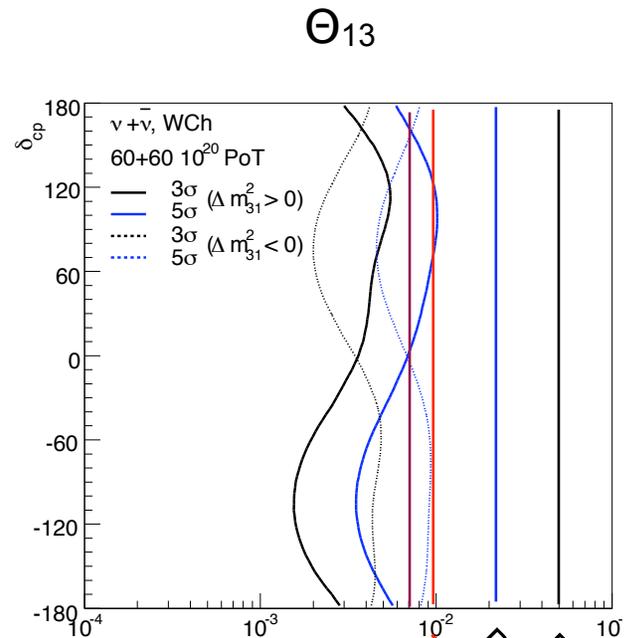
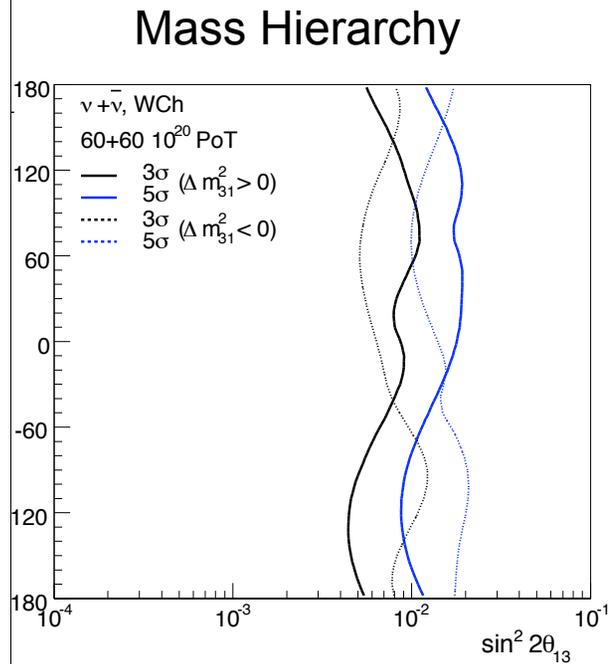
from Mark Dierckxsens  
Milind Diwan  
Mary Bishal

## Determination of CP Phase



# Physics with 300-kt Water Cherenkov Detector & 2 MW Beams @ 120 GeV 3 years each $\nu+\bar{\nu}$

## Exclusion of CP Violation



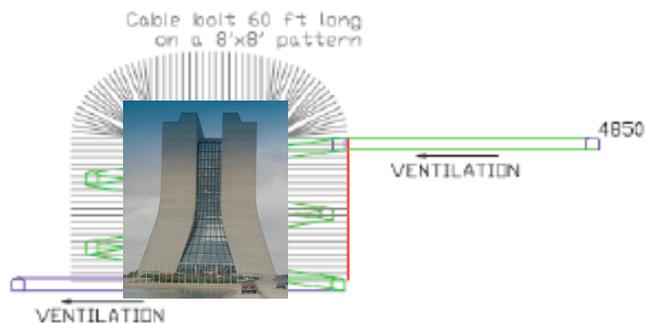
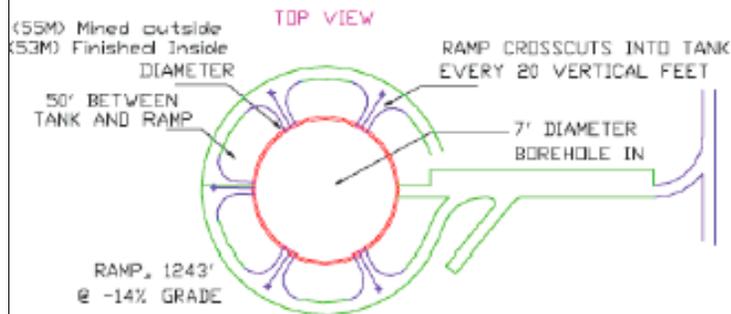
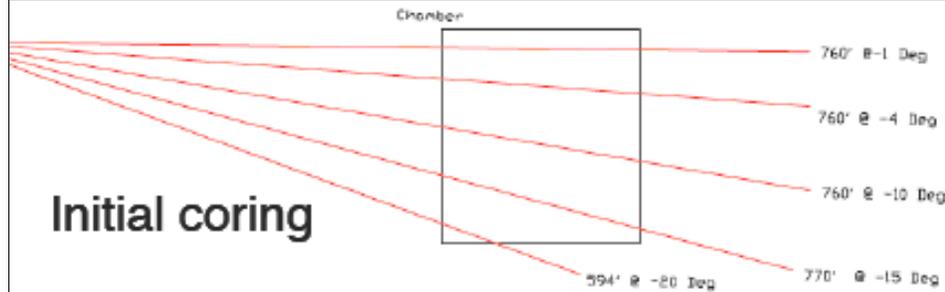
Daya Bay 2012  
 Double Chooz 2012  
 T2K 2012  
 NOVA 2017  
 100kt LAr DUSEL  
 Homestake DUSEL

60x10<sup>20</sup> POT each

Homestake DUSEL

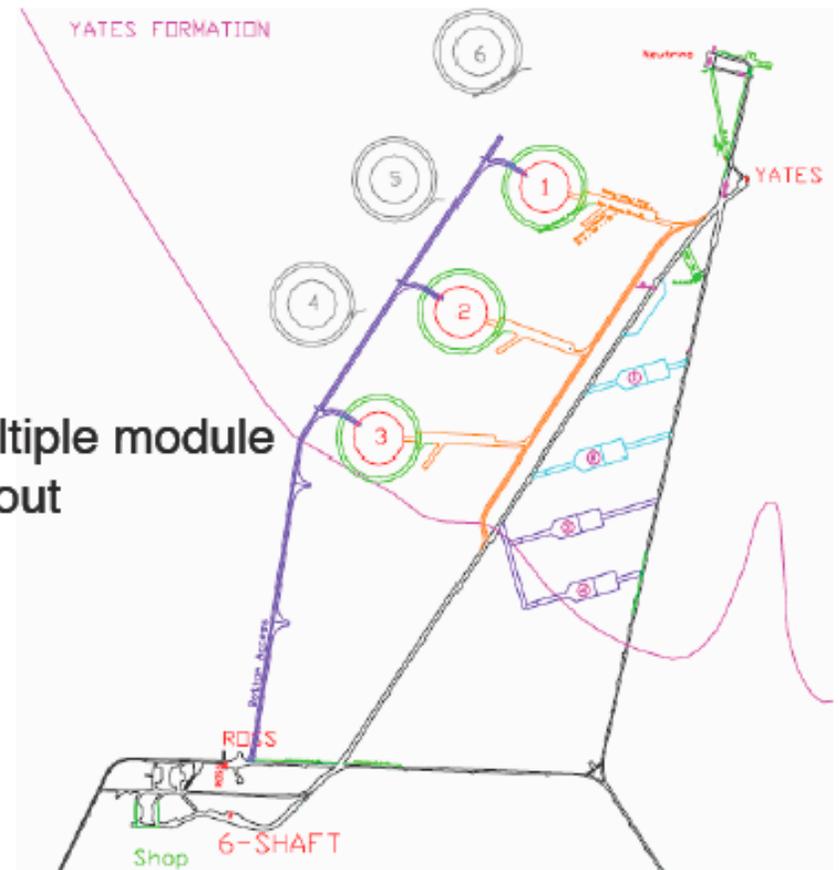
# Modular Approach to Megaton

## Initial coring

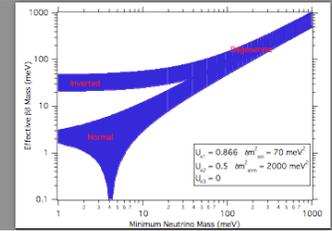


## Single 130,000 ton Module construction

## Multiple module layout



# Physics Motivations: Neutrinos - Neutrinoless Double Beta Decay



Oscillation experiments indicate  $\nu$ s are massive, set relative mass scale, and minimum absolute mass

$\beta$  decay + cosmology set maximum for absolute mass

∴ One  $\nu$  in the mass range:  $\sim 45 \text{ meV} < m_\nu < \sim 2200 \text{ meV}$

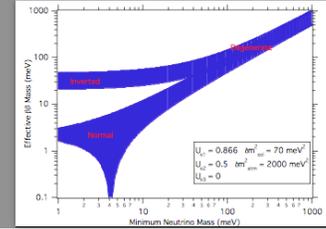
$0\nu\beta\beta$  experiments may determine absolute mass scale

$0\nu\beta\beta$  may establish mass hierarchy, synergistic when combined with accelerator neutrino measurements

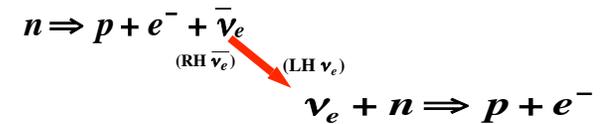
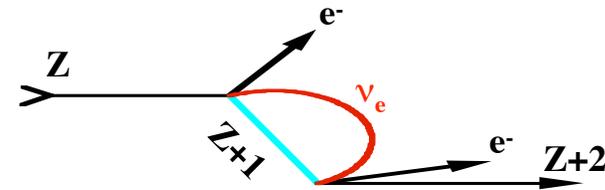
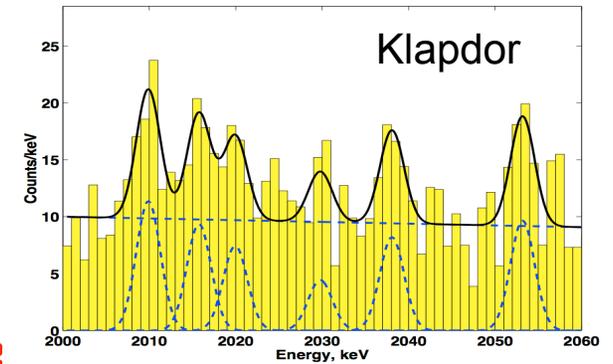
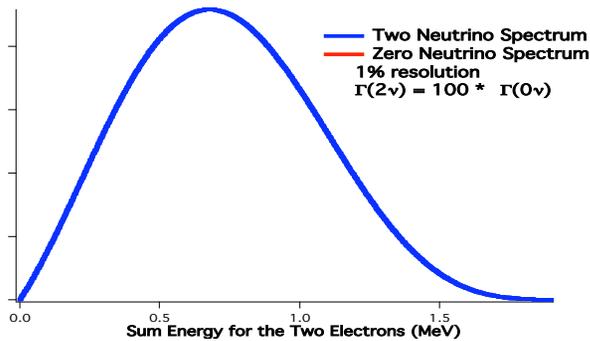
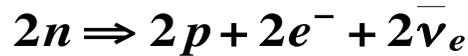
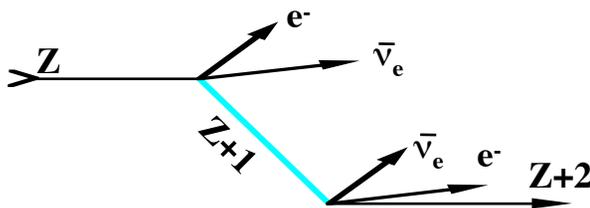
$0\nu\beta\beta$  only way to establish if Dirac or Majorana

Even null results are now interesting and useful

# Physics Motivations: Neutrinos - Neutrinoless Double Beta Decay



$2\nu\beta\beta$

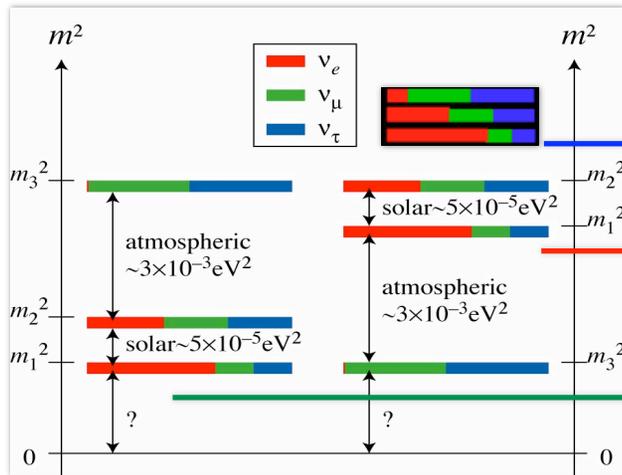
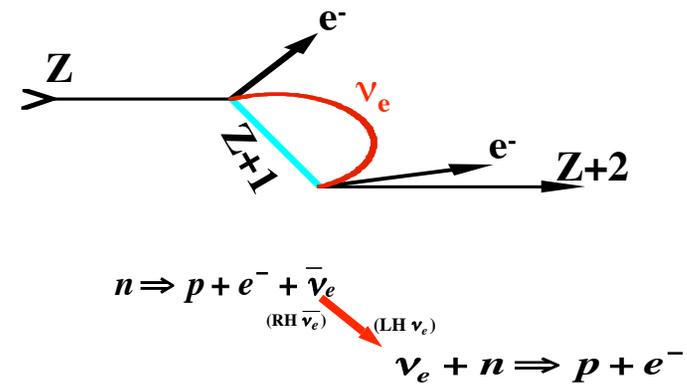


$$[T^{0\nu}_{1/2}]^{-1} = G^{0\nu}(E_0, Z) |\langle m_{\nu} \rangle|^2 |M^{0\nu}_F - (g_A/g_V)^2 M^{0\nu}_{GT}|^2$$

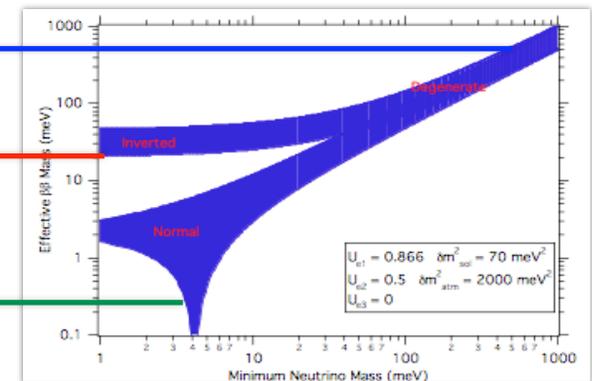
# Physics Motivations: Neutrinoless Double Beta Decay

Requires Shielding (great depth ~ 2500 m), Experimental Support, Access, Stability, Environmental Control

- Well Motivated by  $\nu$  Oscillation Experiments
  - Absolute  $\nu$  mass scale
  - $\nu$  mass hierarchy
  - Dirac or Majorana Nature of  $\nu$
  - Even null results are valuable



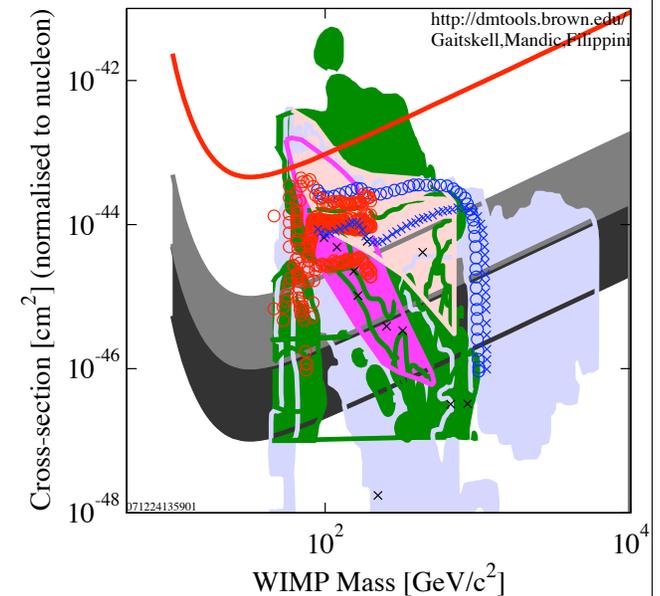
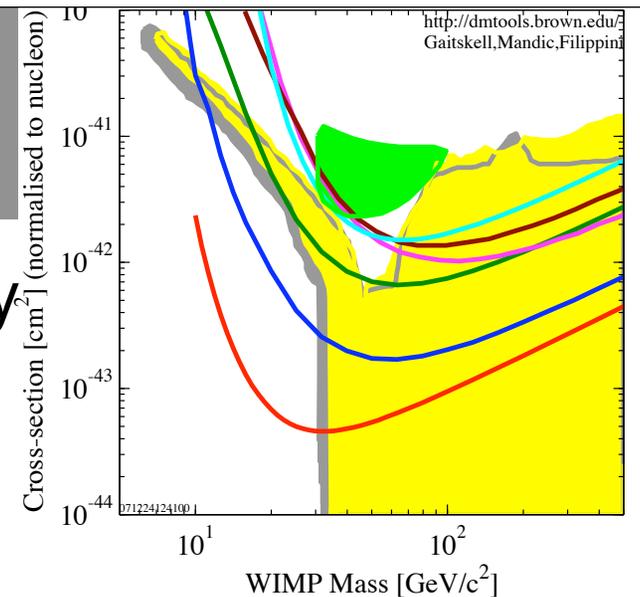
Degenerate  
 ~ 10 - 100 kg  
 Inverted  
 ~ 100 - 1000 kg  
 Normal  
 ~ 1 - 100 T



$$[T^{0\nu}_{1/2}]^{-1} = G^{0\nu}(E_0, Z) |\langle m_{\nu} \rangle|^2 \quad |M^{0\nu}_F - (g_A/g_V)^2 M^{0\nu}_{GT}|^2$$

# Physics Motivations: Dark Matter

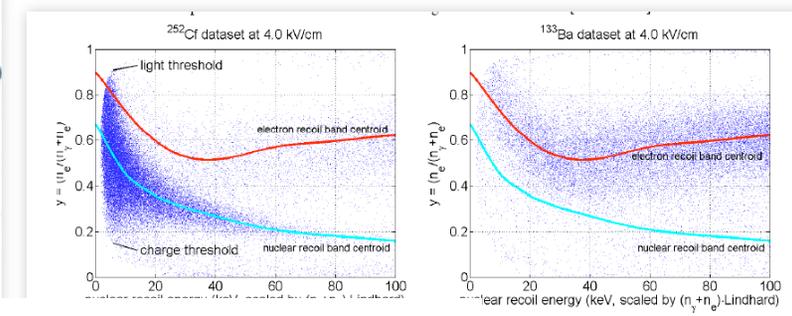
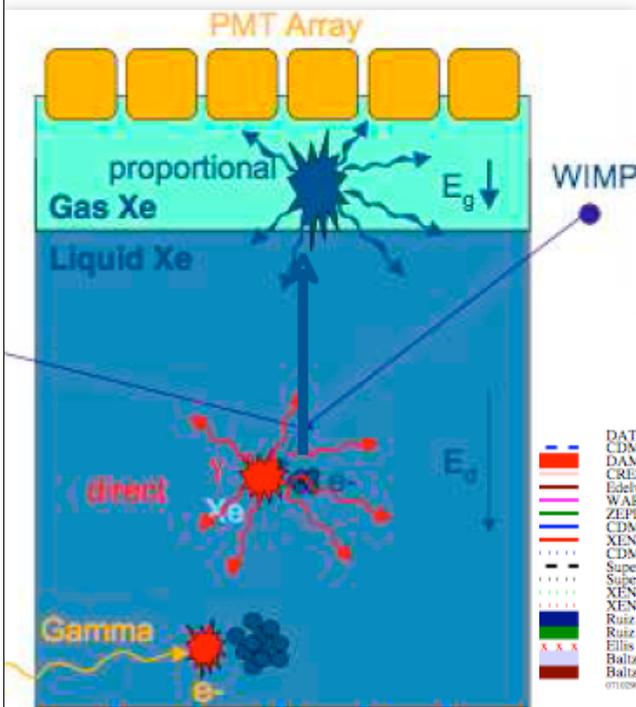
- Strong science motivation for discovery
  - Convergence of particle and astrophysics theory/experiment
- Significant recent advancements in sensitivity
  - US is current world leader in field
- Direct searches testing physics complementarity to accelerator work
  - Also indirect/astro signal searches
- Flagship science at DUSEL
  - DUSEL will ensure continued leadership



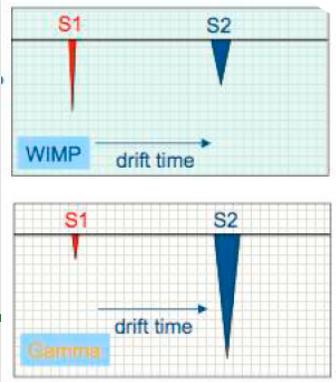
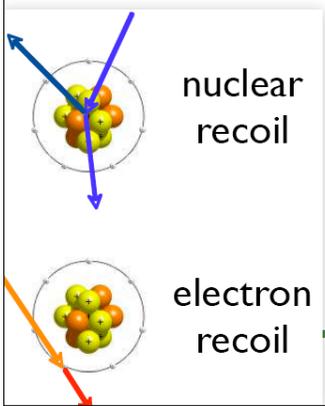
figures from Town Meeting DM working group

# Physics Motivations: Dark Matter

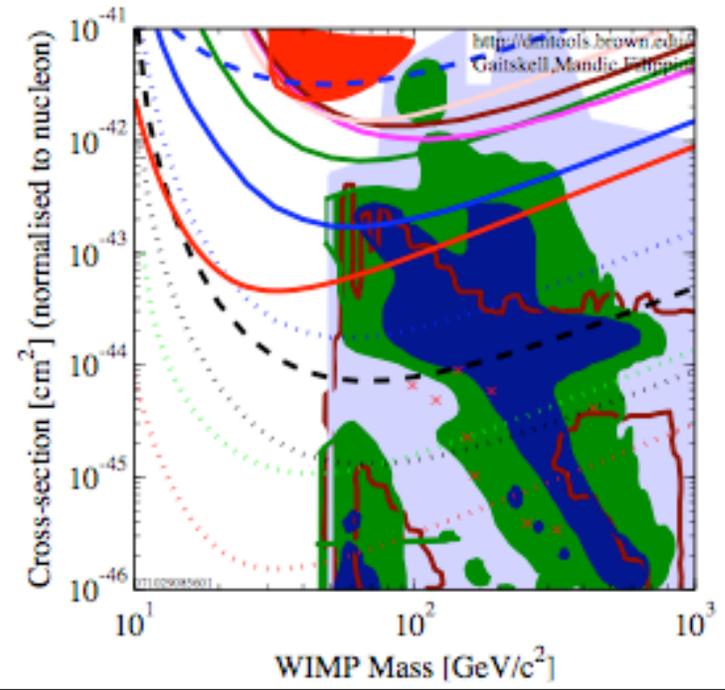
Requires Shielding  
(great depth ~ 2500 m),  
Experimental Support,  
Access, Stability,  
Environmental Control



- DATA listed top to bottom on plot
- CDMS (Soudan) 2005 Si (7 keV threshold)
- DAMA 2000 58kg kg-days NaI Ann.Mod. 3sigma,w/o DAMA 1996 limit
- CRESST 2004 10.7 kg-day CaWO4
- Edelweiss I final limit, 62 kg-days Ge 2000+2002+2003 limit
- WARP 2 3L, 96.5 kg-days 25 keV threshold
- ZEPLIN II (Jan 2007) result
- CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
- XENON10 2007 (Net 136 kg-d)
- CDMS Soudan 2007 projected
- SuperCDMS (Projected) 2 ST @ Soudan
- SuperCDMS (Projected) 2SkG (7-ST @ Snolab)
- XENON100 (150 kg) projected sensitivity
- XENONIT (proj)
- Ruiz de Austri/Trotta/Roszkowski 2007, CMSSM Markov Chain Monte Carlos (
- Ruiz de Austri/Trotta/Roszkowski 2007, CMSSM Markov Chain Monte Carlos (
- Ellis et. al Theory region post-LEP benchmark points
- Baltz and Gondolo 2003
- Baltz and Gondolo, 2004, Markov Chain Monte Carlos



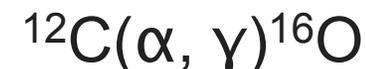
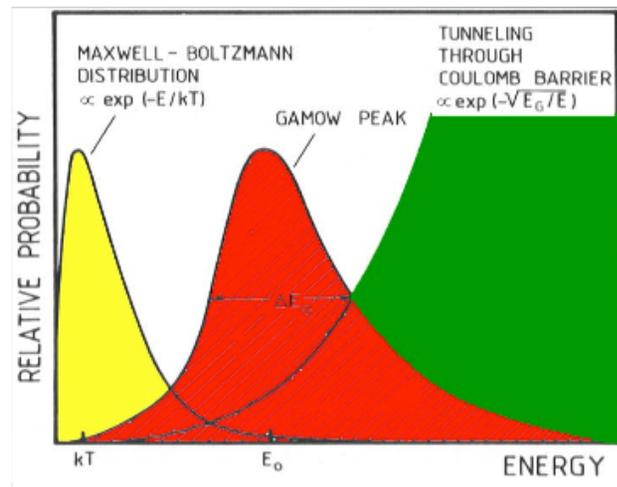
FOM:  
1 ct/T/year



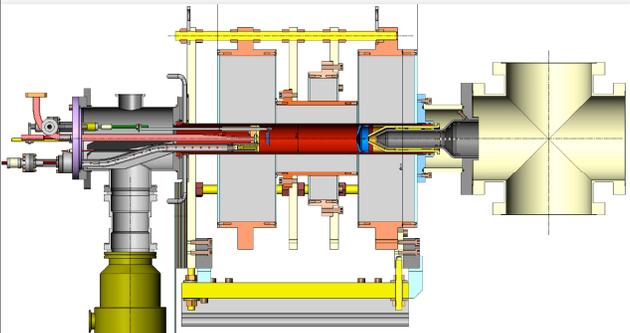
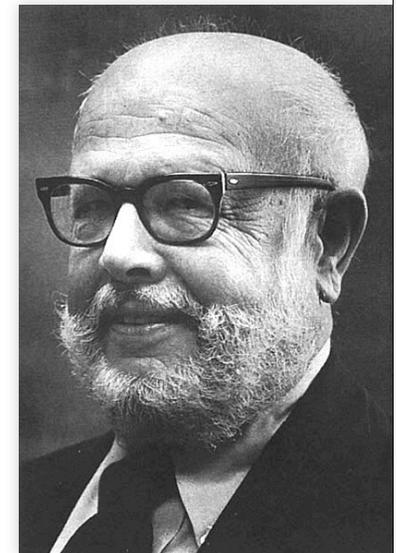
# Physics Motivations: Nucleosynthesis

- $A > 60$  formation in Supernovae,  $\nu$  interactions
- Sources of neutrons for s-, r- processes
- Details of Lower Mass Nucleosynthesis
- pp chain
- CNO

Requires  
Moderate Depth  
(~ 1500 m),  
Underground  
Accelerators,  
EH&S

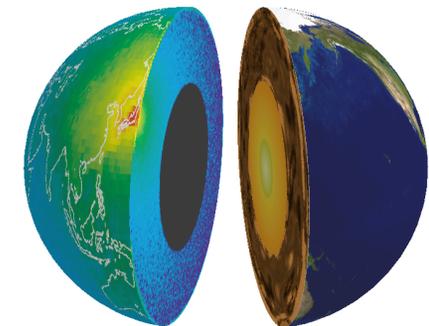
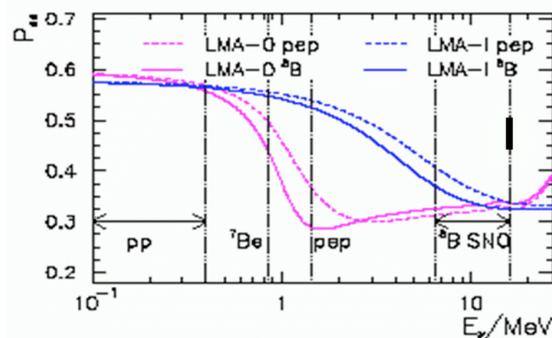
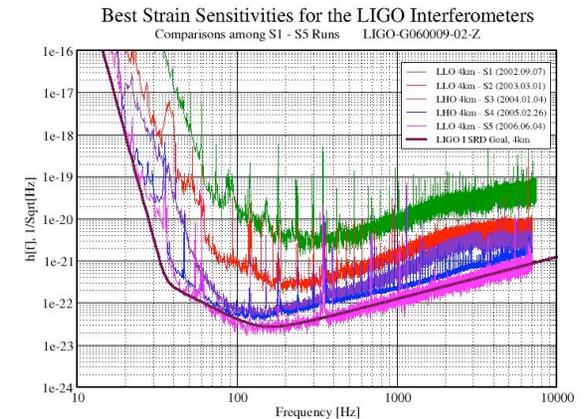


...



# Research in Targeted Fields of Opportunity

- Solar Neutrinos
- Gravity Waves
- Geoneutrinos
- Neutron-oscillations
- ...



$$i\hbar \frac{\partial}{\partial t} \begin{pmatrix} n \\ \bar{n} \end{pmatrix} = \begin{pmatrix} m + V_1 & \delta \\ \delta & m + V_2 \end{pmatrix} \begin{pmatrix} n \\ \bar{n} \end{pmatrix}$$

Concepts for Initial Suite of Experiments - to be revised with community based program

Dark Matter (6-8)

Sanford Lab

4850L

7400L

Neutrinoless  $\beta\beta$

Decay (2 - 3)

Sanford Lab

7400L

Long Baseline  $\nu$  &

Nucleon Decay (2)

300L

4850L

Nuclear

Astrophysics (2)

4850L

Geoneutrinos (1)

4850L

Low Energy Solar  $\nu$

(2)

4850L

7400

Gravity Waves (1)

2000L

Engineering and Excavation Research

4850L

7400L

Scale Effects

4850L

7400L

Active Processes

4850L

7400L

Geobiology

0 - 16,000

Low Background Assay & Materials

300L

4850L

R&D Efforts

Surface

300L

4850L

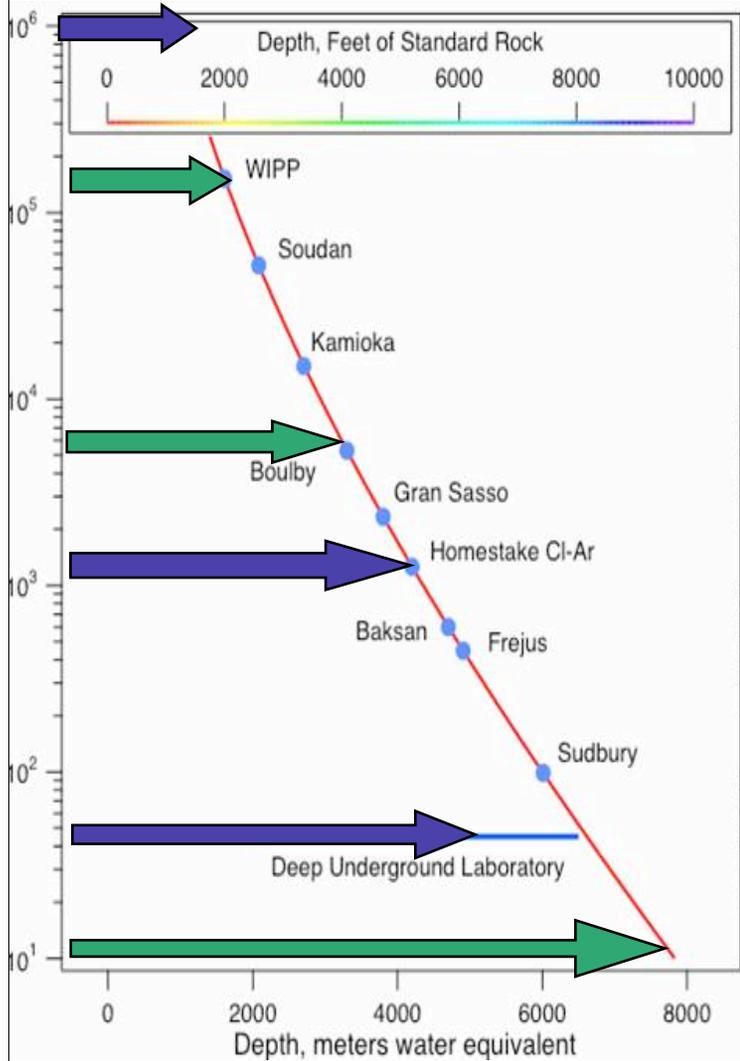
7400L

Education & Outreach

Surface

300L

# Research Campuses



300L R&D,  
E&O 10k ft<sup>2</sup>

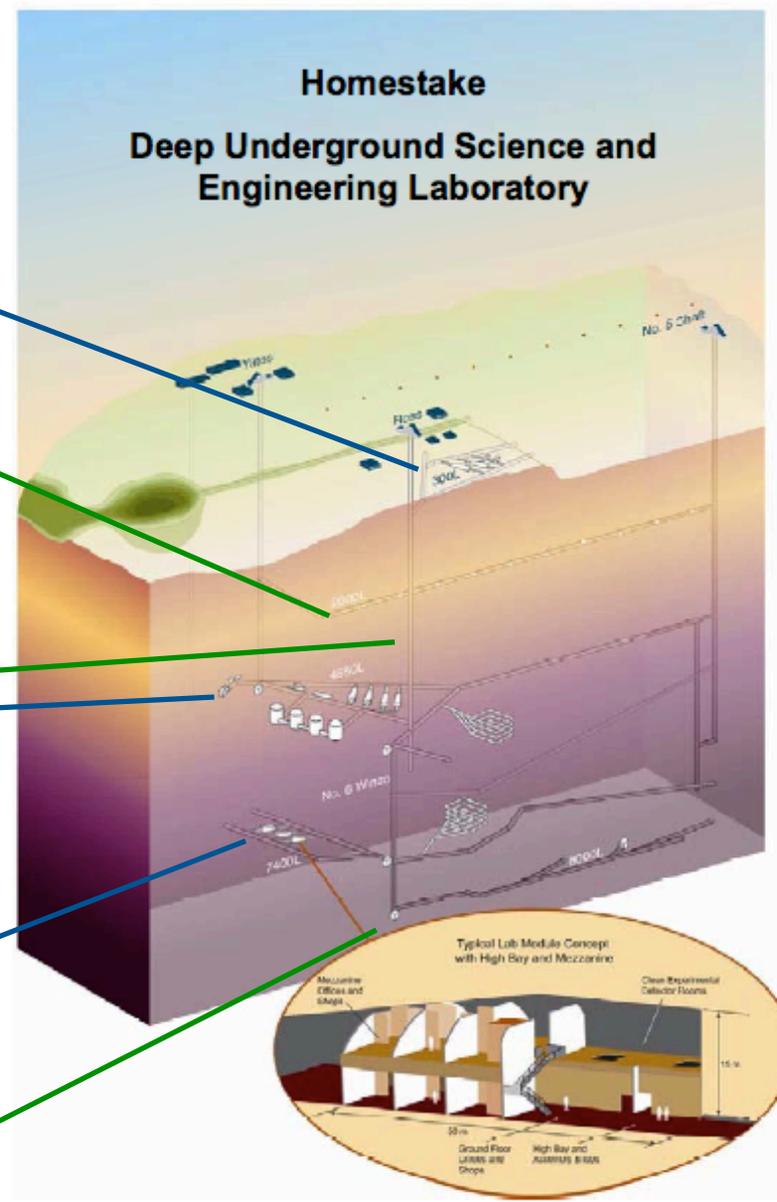
2000L Geo  
Level

3800L Geo  
Level

4850L Major  
Campus  
100k ft<sup>2</sup>

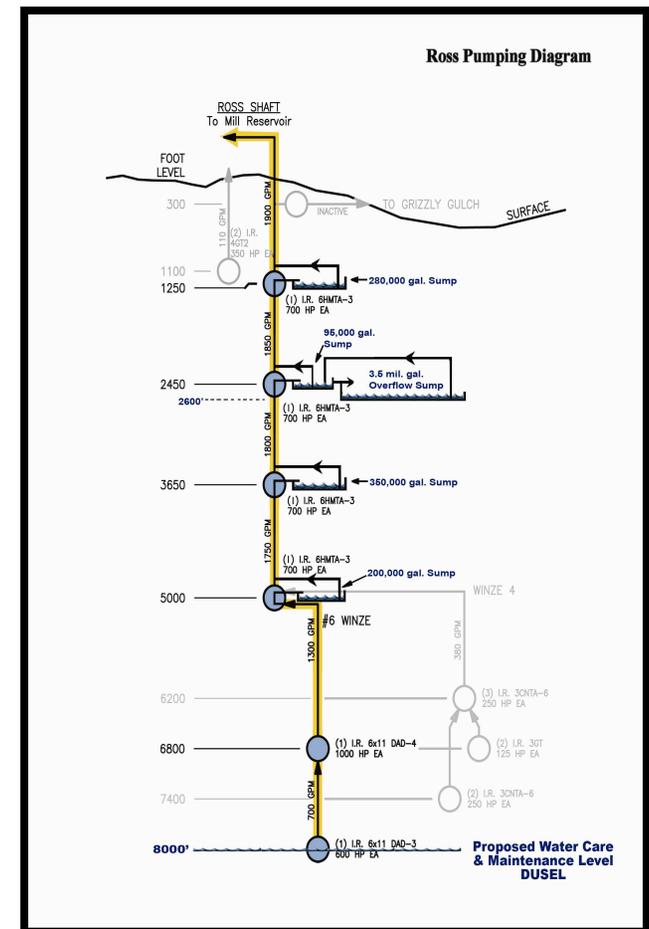
7400L Major  
Campus  
65k ft<sup>2</sup>

8000L Geo  
Lab



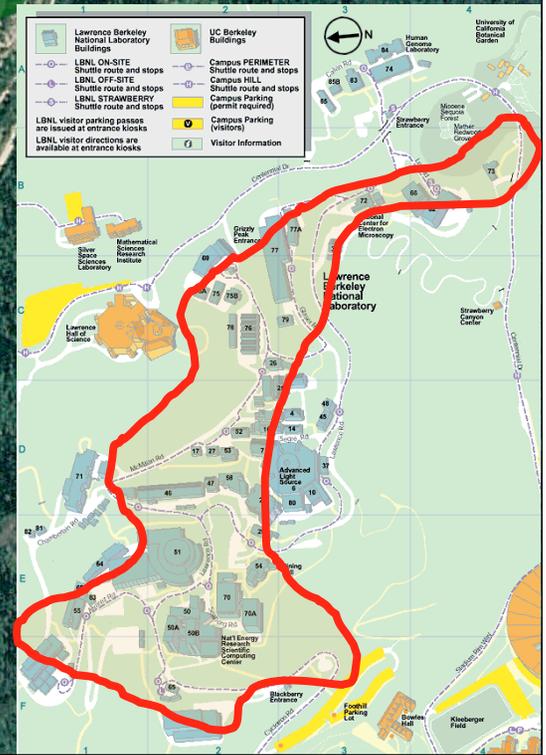
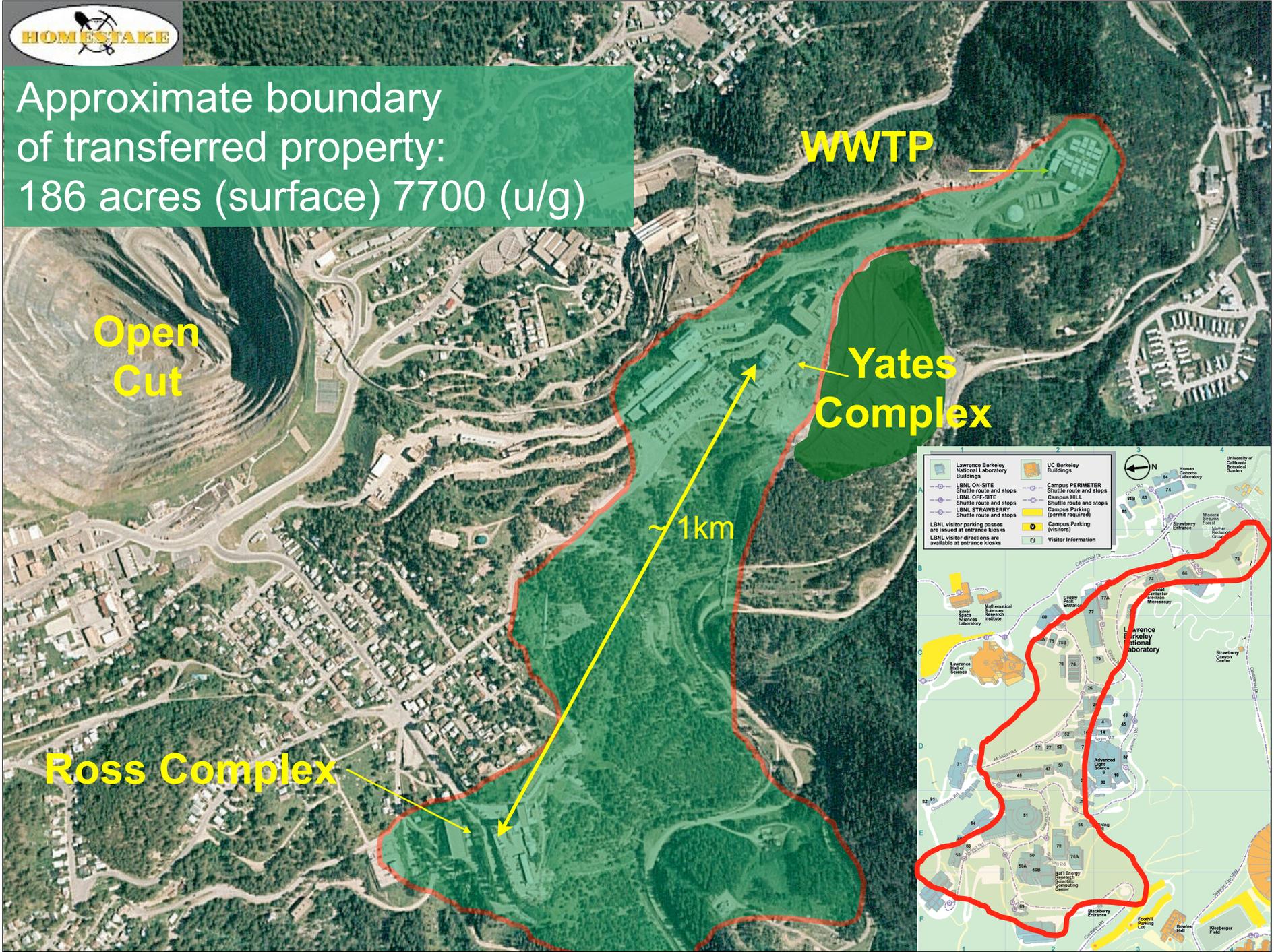
# Progress at the Sanford Lab

- \$115M state-funded effort
- Jose Alonso Lab Director
- Focusing on stabilizing facility and starting early science as Sanford Lab
- Pumped 3.5M G in April & May
- Routine pumping by June
- Access to 4850L by Sept
- Science at 4850L by Dec

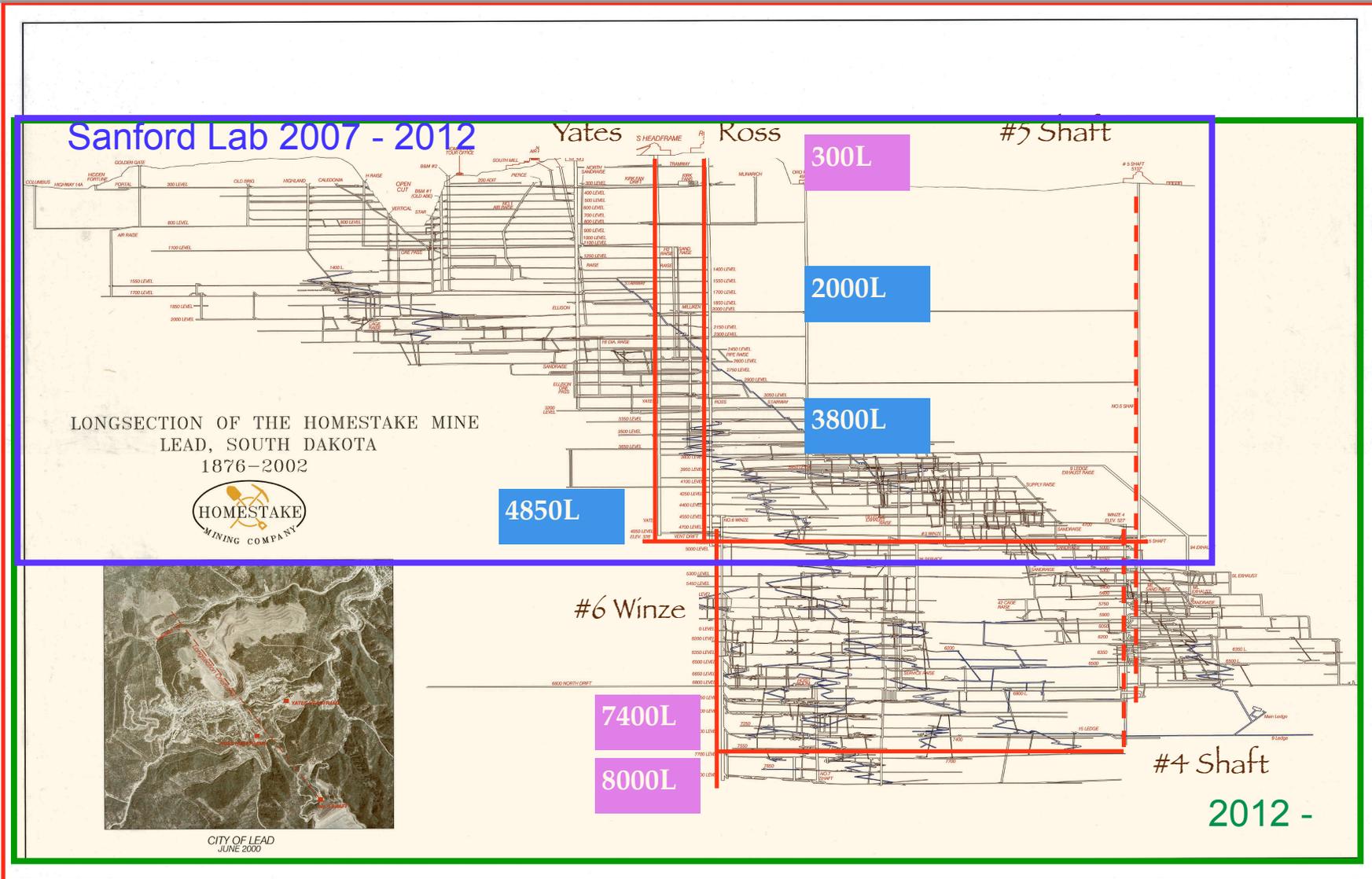




Approximate boundary of transferred property:  
186 acres (surface) 7700 (u/g)



# Phased approach to building DUSEL



A dedicated science facility without competition or interference from mining, transportation, etc.

# Summary

- **World-class Programs**
- **Unique Capabilities in the World**
- **Transformational Experiments Identified**
  - Dark Matter
  - Neutrinoless Double Beta Decay
  - Long Baseline Neutrinos + Nucleon Decay
  - Other Topics and Disciplines
- **Efforts underway at Sanford Lab to prepare the site (\$126M) parallel to DUSEL efforts**
  - phased program for experiments
- **Long-term, Reduced Risk, Well-known Site**
  - tailored access
  - 30+ year horizon providing critical u/g space
  - no competition with other interests